

THE ABSORPTION OF WATER VAPOR BY LEATHER*

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ABSTRACT

A new test method has been developed by which the water vapor absorptive capacity of leather and of synthetic shoe materials can be measured by placing one surface of the specimen parallel to and not more than 10 mm from a water surface. Tests were conducted at the approximate temperature around a shod foot (38°C.) and at 23° and 60°C. At 38°C., tests were also conducted on the same specimens, after taping the surface that, in the shoe, would face the atmosphere or, in the case of insoles, the bottom filler.

This paper deals with water vapor absorption by the shoe components during a 6-hour period only. During this period, the water vapor absorption increased with the temperature, but the increase was greater when the temperature increased from 23° to 38°C. than when it increased from 38° to 60°C. Not surprisingly, water vapor absorption increased sharply during the first hour but thereafter was fairly uniform, which is fortuitous because, normally, sweat flow is greatest immediately after shoes are donned and then it gradually subsides.

In order to approximate conditions of wear the tests are carried out on taped specimens at 38°C. The conclusions reached are that (1) moisture from foot perspiration migrates in vapor form into the shoe components surrounding the foot and condenses there as absorbed water; (2) in general, leather absorbs more water vapor than synthetic shoe materials and usually can keep up with the amount produced by the foot; however, when exertion produces so much water vapor that the capacity of the leather to absorb it as vapor is exceeded the excess vapor condenses as liquid water which is held as free water or as absorbed water in the pores of the leather; (3) shoe comfort depends more on the ability of leather to absorb than to transmit vapor; and (4) the concept of leather as "breathing" is not the characteristic that distinguishes it from synthetic materials.

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INTRODUCTION

The relative humidity of the air surrounding the shod foot is very high. According to a National Bureau of Standards study (1), the air next to the toes or the sole of the foot is saturated with moisture almost immediately after donning shoes or boots. This estimate was made on the basis of the following facts:

- (1) The air volume in a shoe or in the lower parts of a boot is no greater than 100 ml.
- (2) Only 3.4 mg water is needed to saturate 100 ml of air at 90°F.
- (3) When air samples were extracted from the shoes of 12 persons, they were found to be moisture-saturated in every instance.

In more recent measurements made by SATRA,* the air in the forepart of the shoe was found to be saturated with moisture (2a). Results of other studies, however, are somewhat at variance with these findings. In one study (3), the highest value obtained for the relative humidity inside a shoe was less than 80 percent. Another study implies that in some parts of the shoe the relative humidity can exceed 95 percent, in other parts it can be considerably lower (4).

Since the quantity of water sufficient to saturate the air in a shoe is so extremely small — a decrease of 1.0 mg per 100 ml of air at 90°F. causes a drop in the relative humidity from 100 to 70 percent — even the best experimental techniques may give inaccurate values. In fact, when we direct our attention from the air inside the shoe to the shoe itself (which must cope with the perspiration produced by the foot), it makes little difference how close to saturation the air next to the foot is. What is important is whether or not the inner surface of the shoe is capable of absorbing the perspiration at the rate that it is produced.

The question to be answered first, then, is whether perspiration comes in contact with leather as a liquid or as a vapor. Evidently the socks would get moist if they acted as a wick to transport liquid sweat into the leather, but they would remain relatively dry if the perspiration passes through them as vapor which then condenses in the leather. Table I shows that the weight increase found in worn socks is very slight. These investigations support the statement that, under normal circumstances, perspiration is transmitted to the leather in vapor form. Therefore, the quantity of sweat in the shoe is always much greater than that in the sock — according to Table I, it is from five to twenty-five times greater.

The range in the amount of sweat reported in the shoe leather (Table I) should not be surprising since the tests included level walking in laboratories as well as forced marches. The lack of agreement as to the distribution of the sweat pickup between insole and uppers also should not be surprising. In one study (4), the ratio was estimated to be one to one; in another (2b), two to one. In both of the above instances, the footwear tested were shoes. For boots

*Shoe and Allied Trades Research Association (England).

from which less vapor can escape, the ratio would probably have been two to one. Using this ratio, and also the SATRA figures for the leather surfaces active in picking up sweat (2c), it is possible to calculate the quantity of moisture absorbed per hour and per square centimeter of leather surface.

TABLE I
MOISTURE PICKUP OF FOOTWEAR PER 7 TO 8 HOUR DAY

Source of Data	U. S. (1)	England (2b)	Canada (3)	Sweden (4)
Number of individual tests	19	11	not known	14
Sock pickup (gm sweat)	0.3	1.5	2.0	not known
Shoe pickup (gm sweat)	7.5	24.5	10.0	4.0*

*Median value, Table II of Reference (4).

Before doing this, however, we must consider two more facts that emerged from these investigations: first, some areas of the shoe receive more sweat than others (for instance, one part of the insole absorbs about 70 percent more sweat than another part) (4); and, secondly, the sweat flow is highest in the first hour or so and then it gradually declines (2d,4). It is incorrect, although regrettably a common practice, to express sweat flow in grams per hour based on the measurement of absorption over a 7 to 8 hour period. Correct estimates of hourly pickups are shown in Table II.

TABLE II
MOISTURE PICKUP OF SHOES BASED ON
THE ENGLISH AND CANADIAN FIGURES OF TABLE I

AREA Source of Data	VAMPS AND QUARTERS		INSOLES	
	SATRA (2b)	Canada (3)	SATRA (2b)	Canada (3)
Surface, sq cm (2c)	300	300	200	200
Total pickup (ratio 2 to 1), gm	16.3	6.7	8.2	3.3
First hour pickup (30% of total pickup), gm	4.9	2.0	2.5	1.0
Last hour pickup (10% of total pickup), gm	1.6	0.7	0.8	0.3
First hour pickup, mg/sq cm	16.3	6.7	12.3	5.0
Last hour pickup, mg/sq cm	5.4	2.2	4.1	1.7

NOTE: All figures are rounded to the nearest 0.1.

This leads us to two further questions: How does the ability of the leather to absorb these quantities of perspiration from the vapor phase compare with the rate at which the perspiration is produced? Can non-leather materials fulfill as well as leather the demands made on them by the flow of sweat?

It seemed that these questions could be answered by an arrangement whereby specimens of shoe materials are placed close to a water surface and their weight increase recorded at a specified time. The device used allows the underside of the specimens to rest about 10 mm from a water surface. Details of the method are given below. This approach was greatly influenced by the findings of Martin (5) who, in turn, refers to a communication by the American Society for Testing Materials (6).

EXPERIMENTAL

1. *Equipment.* Large desiccators (250 mm diameter) were filled with circular pieces of polyurethane foam rubber soaked with water in which a small quantity of Merthiolate powder No. 22 (Lilly) was dissolved. The air was squeezed from the foam rubber discs until they protruded no more than 5 mm above the surface of the water that reached to about 7.2 cm below the rim of the desiccators. The water surface was $(12.25)^2 \times 3.14 = 470$ sq cm or 73 sq in.

A glass scaffold, essentially an equilateral triangle with sides 200 mm long (Fig. 1), was placed horizontally on the foam rubber. Four clusters of three

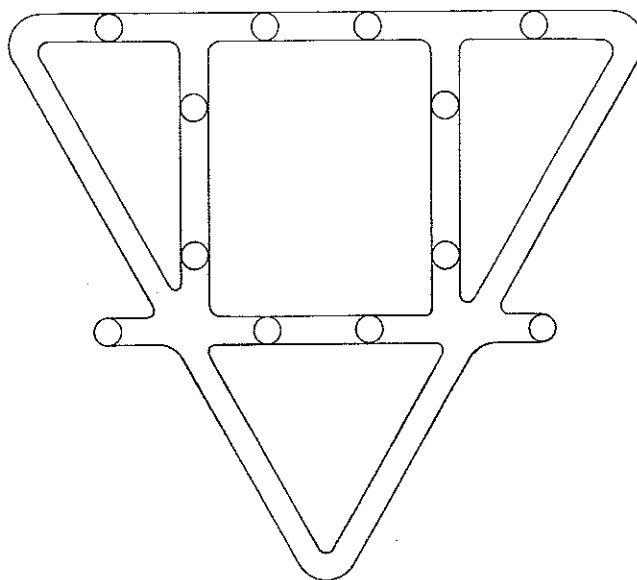


FIGURE 1.—Glass scaffold for airtight humidity chamber.

protuberances each were fused to the scaffold. Circular specimens of shoe materials 3 inches in diameter were placed on these.

The successful operation of an airtight humidity chamber requires that (1) the volume of air space in cubic inches is not greater than ten times the surface area of the solution in square inches, and (2) the total area of the specimens is smaller than the surface area of the solution (6).

The air volume in the lower part of the desiccators was $(12.5)^2 \times 7.2 \times 3.14 = 3530$ cc; that in the dome-like desiccator top was 1200 cc, making a total of 4730 cc or 289 cubic inches. Thus in this equipment the ratio between air volume in cubic inches and water surface in square inches was about 4 to 1. The surface area of four of the thickest specimens was approximately $8 \times 3.8 (3.8 + 0.4) \times 3.14 = 400$ sq cm as compared to a water surface of 470 sq cm, or about 85 percent of the area covered with water. The two requirements were therefore met.

The desiccators were kept at 23°C. (in the conditioning room), at 38°C., which approximates foot temperature (7) (in a large incubator), and at 60°C. (in a forced draft oven). If the conditions for one of the desiccators had to be changed, this was done at least 20 hours before loading it.

2. *Materials.* The materials tested, their thickness, apparent density, water vapor permeability, and specification reference, if any, are given in Table III. These physical properties were determined by known methods (8).

The rawhide was a grain split of cattlehide, acetone-dehydrated at the Natick Laboratories. All of the other materials had been submitted to the laboratories over the past few years by industry. The leathers represented production lots; the synthetic materials, although not identified in the table, have all been well known for several years and have all been used in the civilian market, although their exact share of the market is unknown.

3. *Procedure.* Circular specimens, 3 inches in diameter and of known weight and thickness, were placed on the scaffold with that surface turned downward which, in footwear made from the material, would be nearer to the foot. In one test series, the opposite surface was covered by black electric tape; in the others it remained uncovered.

Separate tests of 1, 2, 5, and 6 hours duration were run because interruptions lowered the humidity of the air in the desiccators and reduced the figures for water vapor pickup.

After opening the desiccators, the specimens were quickly transferred to polyethylene bags from which they were removed one at a time to be weighed to the nearest milligram. They were then placed on a rack in the conditioning room (23°C. at 50 percent R.H.) to dry. Most of the moisture pickup was lost within three hours.

TABLE III
PHYSICAL CONSTANTS OF MATERIALS TESTED FOR WATER VAPOR ABSORPTION

Type of Tannage	Thickness (cm*)	Apparent Density	Water Vapor Permeability (gm/sq m/day**)	Specification
1. Rawhide, cattle	0.155	0.51		
2. Shoe upper materials				
Calf	0.130	0.65	525	MIL-S-13192 (optional)
Kip, Tannery A	0.165	0.67	195	MIL-S-13192
Kip, Tannery B	0.155	0.73	230	MIL-S-13192
Side, Tannery C	0.240	0.68	325	MIL-L-3122
Side, Tannery D	0.230	0.70	495	MIL-L-3122
Side, Sylmer-treated	0.235	0.72	340	MIL-L-3122
Army Retan, flesh out†	0.195	0.83	115	Obsolete
Synthetic	0.155	0.52	270	—
3. Insole material				
Civilian, Tannery A	0.320	0.93	230	
Civilian, Tannery B	0.400	0.92	320	
Military	0.370	0.82	350	MIL-I-570
Leatherboard	0.330	0.95	75	
Synthetic A	0.340	0.58	630	
Synthetic B	0.315	0.68	170	
Synthetic C	0.330	0.70	225	

*To nearest 0.005 cm.

**To nearest 5 gm/sq m/day.

†Worn, with shoe polish applied to flesh surface.

Fluctuation in the weights of the specimens was held to a minimum by closely controlling the temperature and relative humidity of the conditioning room. Records of the weights were kept so as to be sure that the specimens returned to their original weight after each test.

Results were calculated (a) in mg/sq cm, by dividing the weight increases in mg by the area of the circular specimens, which was assumed to be $(1.5)^2 \times 3.14 \times 6.45 = 45.6$ sq cm, and (b) in mg/cc, by dividing (a) by the thickness of the specimens in cm.

RESULTS

1. **Preliminary Study Results.** The test method used was developed as a convenient means for gathering information on initial water pickup only; therefore the tests were not continued until equilibrium was reached. The usefulness of the method was assured by various preliminary studies, some of which were run to find out whether the pickup of water vapor is affected when a single specimen is placed in the desiccator rather than loading the desiccator to capacity. No differences in water pickup were found at 38° and 60°C. but differences were observed at 23°C. (Table IV). It is seen that the upper leather showed differences only during the first hour while with insole leather differences persisted up to the sixth hour.

TABLE IV
WATER VAPOR ABSORPTION OF LEATHER IN MG/CC AT 23°C.

	Hours			
	1	2	5	6
1. Upper Leather				
Full Load	22	47	73	85
Single Specimen	28	46	72	86
2. Insole Leather				
Full Load	16	25	49	55
Single Specimen	20	32	57	62

In this preliminary study, the surface of the specimen that ordinarily is next to the sock faced the water in the desiccators. This was the general rule during the experiments. However, a small test was run to find out whether this rule is really important. The results in Table V show that none of the materials picked up appreciably more water on one side than on the other.

TABLE V
WATER ABSORPTION AT 38°C. IN 6-HOUR TEST

	Surface Toward Sock During Wear			
	Next to Water (mg/sq cm)	Away from Water	Next to Water (mg/cc)	Away from Water
Calf	20	20	157	154
Kip	20	20	138	134
Side	25	25	107	107
Insole, Tannery A	42	42	130	130
Insole, Tannery B	44	43	111	107
Military Insole	36	38	97	102
Synthetic Insole C	12	12	38	38

2. Final Test Results.

a. *Insoles*—The water vapor absorption of leather and non-leather insoles during a 6-hour period is illustrated in Figure 2. The three single-line curves signify the water vapor absorption means, in mg/sq cm, of the three leather insoles (civilian A and B and military) of Table III and the two shaded areas

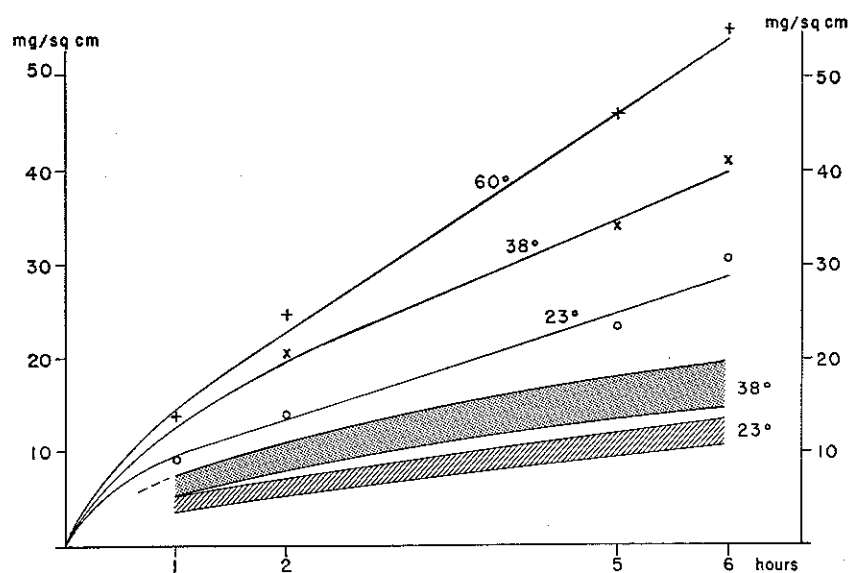


FIGURE 2.—Water vapor absorption in mg/sq cm.
Curves: Means for three insole leathers (2 vegetable and 1 chrome vegetable at 23°, 38°, and 60°C.).
Shaded Areas: Range for three synthetic insole materials at 23° and 38°C.

cover the range of water vapor absorption characteristic of the three synthetic insoles (A, B, C) of Table III at 23° and 38°C. Their water vapor absorption at 60°C. was nearly the same as at 38°C. and therefore could not be separately shown.

b. *Uppers*—The figures obtained with the upper leathers were higher at 38° than at 23°C., but there was not a consistent further increase at 60°C. The two leathers showing consistent increases at 60°C. were the side leather and the Army Retan and the increase was substantial only in the Army Retan, which

TABLE VI
WATER VAPOR ABSORPTION (IN MG/CC) AT 23°, 38°, AND 60°C.

°C.	Hours											
	1			2			5			6		
	23	38	60	23	38	60	23	38	60	23	38	60
Rawhide, cattle	45	57	59	66	82	92	115	144	139	140	158	161
Calf	52	59	51	78	109	108	103	143	148	118	158	154
Kip	38	55	47	58	75	79	88	124	116	101	134	129
Side, untreated & Sylmer treated	29	38	40	47	68	74	75	97	106	87	107	113
Army Retan	37	42	48	48	64	81	88	92	119	96	110	150

contains large quantities of vegetable extracts, resembling insoles in this respect. The sharp rise in the rate of water vapor absorption by insoles at 60°C. over the rate at 38°C. is shown in Figure 2. In general, the figures for rawhide are close to those for calf and both from the start were higher than the rest.

3. **Taped Uppers and Insoles.** The idea of using electric tape as a barrier to water vapor absorption was tested on a vegetable insole taken from an unworn dress shoe with the bottom filler attached. The total thickness of this

TABLE VII
WATER VAPOR ABSORPTION AT 38°C. (IN MG/SQ CM) BY INSOLE
WITH BOTTOM FILLER ATTACHED

	Hours of Exposure			
	1	2	5	6
Untaped	13	20	33	38
Taped	12	18	31	37

specimen was 0.75 to 0.90 cm. The results in mg/sq cm were obtained at 38°C. on the untaped specimen and on the same specimen after taping the bottom filler surface (Table VII). Taping lowered the water vapor absorption by only 1 to 2 mg/cc. This small difference demonstrated that taping can be used to simulate the effect of a bottom filler.

The taping of the grain surface of leather and synthetic uppers and of the flesh surface of various insole materials was investigated at 38°C. only. A few results, again in mg/sq cm, are shown in Table VIII. More illustrative is Figure 3, which shows the results for untaped and taped materials. Here the unit employed is again mg/cc.

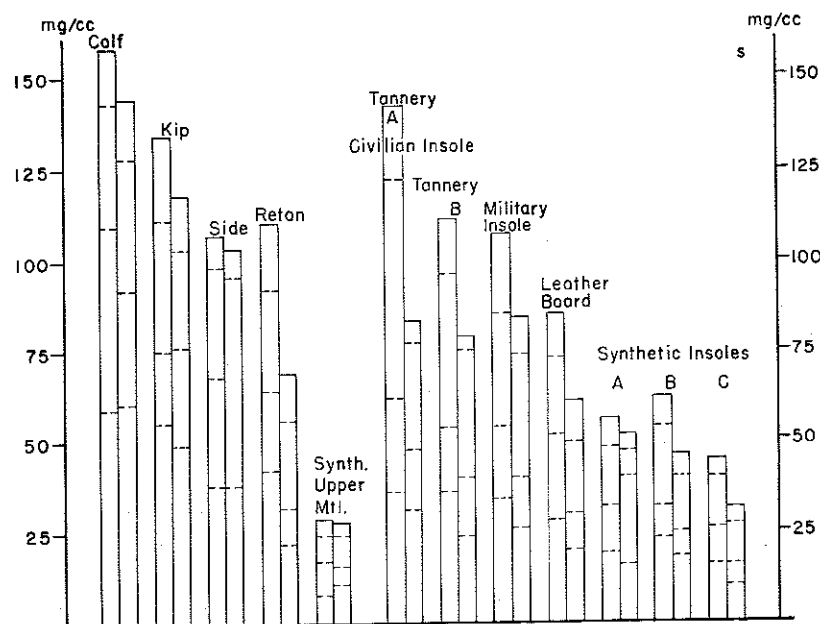


FIGURE 3.—Water vapor absorption (in mg/cc) of shoe materials at 38°C.
 Bars on left — untaped. Bars on right — taped.
 Broken lines — after 1, 2, and 5 hours. Solid lines — after 6 hours.

DISCUSSION

Factors Influencing Absorption.

When specimens of footwear materials were tested at 23°, 38°, and 60°C., it was found that, at 23°C., the number and type of specimens influence the rate of absorption (Table IV). At 38° and 60°C. no such influence was observed. It is not possible, therefore, to use the method at 23°C. and to arrive by extrapolation at values that can be expected at 38°C. Another condition that

influences the rate of absorption is whether or not the surface that is *not* placed next to the water is taped (Table VIII and Figure 3).

TABLE VIII
WATER VAPOR ABSORPTION (IN MG/SQ CM) AT 38°C.
DURING FIRST AND SIXTH HOUR

	With Surface Normally Away From the Foot			
	Untaped		Taped	
	First Hour	Sixth Hour	First Hour	Sixth Hour
1. Shoe Upper Materials				
Calf	7.7	2.0	7.8	2.0
Kip	8.7	2.1	8.4	2.4
Side, untreated & Sylmer-treated	8.8	2.6	8.7	2.8
Army Retan (flesh-out)	8.2	3.5	4.2	2.5
Synthetic	1.8	0.5	1.9	0.4
2. Insole Materials				
Leather (means of vegetable and chrome vegetable)	12.4	6.9	10.0	2.5
Leather Board	9.2	3.9	6.5	3.3
Synthetic A	6.5	3.0	5.4	1.7
Synthetic B	7.4	2.8	5.7	2.0
Synthetic C	5.2	1.7	3.4	1.1

Taping the surface that is away from the water is justified in the case of shoe uppers because it approximates more closely the conditions of wear when water vapor permeability is inoperative, as, for instance, when the atmospheric humidity is near 100 percent or when frequent polishing has clogged the pores near the outer surface. Taping insole materials is also more realistic because insoles in shoes are placed over a bottom filler that is as impermeable a barrier as the tape used to simulate it (Table VII).

Taping the surface away from the water resulted in less water vapor absorption but, as Figure 3 shows, the differences were small in some instances but large in others. Among the materials that showed conspicuous differences between the taped and untaped specimens were the Army Retan and the insoles made from leather and leather board. Here the differences usually appeared during the first hour of the test. A notable exception is the civilian Insole A, for which the difference between the taped and untaped specimen was small at first but later increased until it was very great after 6 hours, when the test was terminated.

Measurement of Absorption.

It follows from these observations that the only reliable guide to the behavior of a material in the shoe is to determine its water vapor absorption at 38°C. on taped specimens and to use data based on the first and final hours of a 6-hour test — 6 hours being the span of time that can be more easily fitted into a working day than can 7½ to 8 hours excluding time for the series of weighings required before and after the experiment itself.

When thin and thick materials are being compared, it is of interest to report the results in units of *volume*. Thus calf, which was, on the average, 23 percent thinner than kip (Table III), has lower values than kip in Table VIII, where the unit is mg/sq cm, and higher values than kip in Figure 3, where the unit is mg/cc.

In regard to the question of which is greater, sweat flow into the shoe or water vapor absorption, the answer must be calculated in units of *area*. Such figures for the sweat pickup by shoes are provided in Table II and for shoe materials in Table VIII. The significant figures in Table II are those for the first and final hours, in mg/sq cm, and the important figures in Table VIII are those for the taped specimens. A comparison of these figures is best made by means of the bar graphs in Figure 4, where the shaded bars signify the results of actual wear tests and the unshaded bars the results obtained in this laboratory.

From Figure 4 we learn that:

(1) In regard to the upper leathers, the water vapor absorption was comparable with the Canadian test conditions, with the exception of the flesh-out Army Retan, which was the only upper leather that, after taping, absorbed markedly less water vapor than before, but was considerably below the sweat flow into the shoes of the more severe SATRA test.

(2) The synthetic upper material could not absorb nearly as much water vapor as was produced by sweat in the Canadian, not to mention the SATRA test.

(3) The leather insoles absorbed more water vapor than was produced in the Canadian test but not as much as was produced in the SATRA test.

(4) Two of the three synthetic insole materials (A & B) and the leather board could absorb as much water vapor as was produced in the Canadian test but the third synthetic insole material (C) could not.

In summary, we find essentially two situations: one in which the water vapor absorption of the shoe material is high enough for the transmittal of all the sweat as vapor, and one in which some sweat flows toward the shoe and is picked up as liquid. This latter situation occurs in leather footwear only if the conditions of wear are extreme, but it is frequently associated with non-leather footwear. The water, in such a case, is present as free water and not in any way bound to or absorbed by the leather fiber or synthetic material. Evidently, comfort

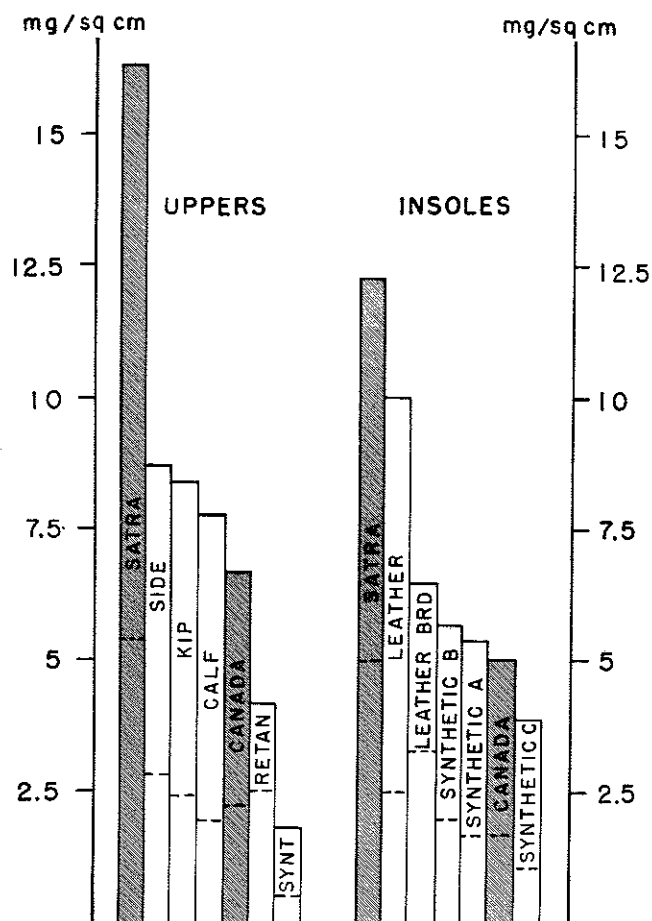


FIGURE 4.—Water vapor absorption (in mg/sq cm) of taped specimens of shoe materials at 38°C. compared with estimates of moisture pickup by footwear in two wear tests.

— Solid lines — during first hour.
 - - - - - Broken lines — during final hour.

is associated with the absence of liquid sweat. Changing from a shoe with a high water vapor absorption to a shoe with a low water vapor absorption gives the wearer the impression that he is "sweating more." There are measures that will minimize this effect for instance by lining such a shoe with leather, using a leather insole, or, finally, increasing its water vapor permeability.

Water Vapor Transmission.

In the past, water vapor transmission has been the one property that has been considered to be leather's greatest virtue and therefore this property has

been the object of many investigations. However, its importance probably is exaggerated. Water vapor transmission cannot come into play the moment a shoe is put on. First the leather must reach an equilibrium with the moist air inside the shoe. In other words, water vapor cannot travel through the capillaries in leather without first moistening the fibers. Very often this moisture cannot be discharged at all, as in humid weather or when the leather has been frequently polished, a condition which drastically affects water vapor permeability by clogging the pores near the grain surface. Finally, the only escape route for water vapor is through the uppers and these comprise about 60 percent of the surface surrounding the foot.

We can see from Table III that water vapor permeability is not a characteristic of leather only; the non-leather materials listed also transmit water vapor. We cannot explain how this is accomplished in all of the synthetic materials but we have found that some have channels large enough for air to pass through at pressures lower than is required for leather. The synthetic upper material, incidentally, behaves like leather: at 10 inches of water pressure, no air can pass through either of them.

What this means in popular language is, of course, that "breathing" is not unique to leather and it is not related to air porosity as is suggested by a term ordinarily associated with the inhaling and exhaling of air. It appears, in fact, that the leather and shoe manufacturers have been beaten at their own game. Unfortunately, no catch phrase of similar simplicity and suggestive force offers itself for that property of leather, water vapor absorption, which emerges as more distinctive and, so far, apparently more difficult to achieve.

CONCLUSIONS

In this new method of measuring the water vapor absorption of leather and synthetic shoe materials under conditions approximating those found in footwear, results significant for comfort are obtained at 38°C. However, this method has also been used to gather data at other temperatures (23° and 60°C.) to demonstrate that, under test conditions for a period of at least 6 hours, the higher the temperature the more water vapor is absorbed. By using knowledge gathered in previous wear tests, conclusions are drawn as to the comfort offered by the various shoe components under slight stress as well as during heavy exercise. Under either condition, leather uppers and insoles score better than synthetic materials. The advantage of leather is that it creates the feeling of dryness in a shoe or boot by absorbing in vapor form most if not all of the perspiration as fast as it is produced. On the other hand, when most of the perspiration remains liquid, the wearer is likely to complain about a wet or clammy feeling.

ACKNOWLEDGMENTS

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DISCUSSION

RICHARD N. JONES (A. C. Lawrence Leather Company): Thank you, Dr. Seligsberger, for this informative paper.

With the introduction of more and more synthetic shoe-making materials, the tanner is taking a closer look at leather's many virtues in order to maintain his competitive position. In this regard, the subject of foot comfort ranks pretty high on the list — and sweat removal, or breathing, or whatever you choose to call it is a most important comfort factor.

Dr. Seligsberger's paper deals with the importance of the water vapor absorption phase of this process. His test results show that leather excels in the ability to absorb water vapor. He has reasoned that since many synthetics have a vapor transmission capability equal to leather, then leather's superior absorption characteristic must be responsible for the fact that leather uppers and innersoles have scored higher in foot comfort tests. He further concludes that the vapor transmission capability of leather has apparently been exaggerated.

I would like to pose a question or two concerning the relative importance of the factors related to leather's ability to breathe. I believe most people subscribe to the fact that the breathing process consists of three phases:

First — moisture absorption either in the form of vapor (as Dr. Seligsberger has measured) or as liquid.

Second — transmission of vapor to the outer leather surface.

Third — dissipation of the vapor by evaporation.

Initially it is possible to maintain foot comfort with only the first phase (that of absorption) operating. If the second and third phases are not functioning, however, there presently comes a time — as your results show — when the rate of absorption falls off. Consequently, people who are active on their feet cannot expect maximum foot comfort until the transmission and evaporation phases are allowed to come into play. From this point on, the curtailment of any of these phases will cause the total leather breathing process to suffer accordingly.

You commented on how the higher initial rate of absorption coincides with the higher initial rate of sweat production. The conditions of your test method were of course not intended to consider the transmission or evaporation phases. I suspect this is responsible for the absorption rate decreasing with time.

In practice, however, if all three phases of the breathing process are functioning, wouldn't you expect that the absorption rate would maintain itself more nearly at the initial rate you found rather than falling off so noticeably?

If this is the case, then, doesn't it point up the considerable interdependence that exists of one phase upon another, making it difficult to justify any conclusion that the vapor transmission characteristic of leather has been exaggerated?

DR. SELIGSBERGER: The answer to the first question is that in the course of the day the demands on the leather are decreasing as the sweat production is falling off, provided the wearer maintains about the same activity throughout. Vapor transmission figures that are published refer to untreated leather, not to leather that has been frequently polished and has lost much of its ability for transmitting it.

Turning to the second question, over half of the materials discussed in the paper were not upper but insole materials which can only *absorb* water vapor but are prevented from transmitting it by the liberal use of bottom filler and cement underneath. Toe caps, lining leather and counters restrict vapor transmission through the upper part but allow — with the exception of the toe caps — vapor absorption. I mentioned already that polishing reduces transmission. Therefore, I believe, I am justified in emphasizing absorption over transmission.

J. E. KENNEDY (Defense Research Medical Laboratories, Toronto, Ontario, Canada): Mr. Chairman, we have carried out some tests in desiccators where

the humidity was controlled in the manner outlined in Dr. Seligsberger's paper. When 4 specimens of 3 inch diameter insole leather (conditioned at 50 percent R. H., 73°F.) were placed in the desiccator at 73°F. (room conditions) the relative humidity was decreased from greater than 95 percent to 55 percent and returned to 72 percent in the next six hours. At a temperature of 105°F., the decrease was from greater than 95 percent R. H. to 84 percent R. H. and in six hours the R. H. returned to 92 percent. Hence there is reason to question whether the water vapor absorption of the leathers was observed in atmosphere of "near 100 percent relative humidity," and whether the actual absorption was representative of the leather or of the atmosphere.

A second point that requires further explanation is the uptake by the leather samples in the first and sixth hours with "one side taped" and in the "untaped" state (Table V). These uptakes observed by Dr. Seligsberger are almost identical for most of his leathers. On insole leather, we find that the uptake rate in the first half hour is in the ratio 2:1 when two sides of the leather sample are absorbing water vapor over that when one side only is absorbing. In the sixth hour, this ratio is 3:4. This rate change is not apparent in Dr. Seligsberger's data. (These observations were on insole leather conditioned at 0 percent R. H. and 70°F., then transferred to 90 percent R. H. at 90°F.)

While Dr. Seligsberger reports a very pronounced "temperature effect" on water vapor absorption by leather, this is not found on most organic materials such as wool, cotton and hair, nor has it been observed by other workers in leather studies. However, in spite of these comments, Mr. Chairman, may I say how much a method for measurement of water vapor absorption by leather is needed, especially at a time when synthetic materials are being introduced into shoe fabrication. In some synthetics the water vapor transmission characteristic of upper leather has been matched, but the high water vapor absorption capacity of leather has not. Both of these properties appear necessary to produce an acceptable shoe; a method which will clearly differentiate the natural leather from the synthetic in its water vapor absorption property is required and development of this (by the ALCA) would be most welcome.

W. CECIL HENRY (Ontario Research Foundation, Toronto, Ontario, Canada): It seems to me that Dr. Seligsberger may be optimistic assuming that the air in his desiccator remains saturated during the six hours when leather samples are under test.

It has been shown that desiccators or small enclosed chambers are satisfactory for the maintenance of precisely known humidities only when the samples absorb a negligible amount of water vapor.

I would like to ask Dr. Seligsberger if he has made any measurements of the actual relative humidity in his desiccator when leather samples were present.*

*Measurements made by the author in answer to this question revealed that the relative humidity in percent was as follows:

Time after Loading Desiccator with Four 3" Discs	At 23°C.		At 38°C.	
	Vegetable Insole	Chrome Side	Vegetable Insole	Chrome Side
20 min.	92	82	98	94
1 hour	88	82	94	89
2 hours	89	84	95	91
6 hours	93	89	97	97

A new grey narrow range sensing element of Hydgrodynamics Inc. was used for these measurements.